

The functional morphology of the superior articular processes of the lumbar vertebrae

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INTRODUCTION

A clear description of the functional significance of the superior articular processes of the lumbar vertebrae has existed for many years. According to Fick (1911) the articular processes limit rotation, or act as 'guide rails' for movement. These suggestions are based on a consideration of the movements of individual segments, and are mostly the result of observing the form of isolated macerated vertebrae. The part played by the ligaments and deep muscles of the column has apparently been largely or completely ignored.

A great deal of research has been carried out on the functional morphology of the bodies and neural arches of the vertebrae, and a representative collection of titles can be found in the article by Schlüter (1965). This author, however, excluded the articular processes from his work on account of their small size, and because their uncertain relationship with the muscles and ligaments had been insufficiently investigated for his purpose. All the same, there exists a number of predominantly general and mostly purely theoretical accounts of the relationship between structure and function in the articular processes (Lutz, 1967; Pfeil, 1971; Putz, 1976, 1977, 1981).

Very recently (Kummer, 1981, 1982) has presented an account, albeit principally static, of the function of the vertebral joints, and the team led by Hille & Schulitz (1983) has at last produced valuable information on the distribution of pressure over the joint surfaces during flexion of the body in the sagittal plane.

The object of the present work is to apply the detailed knowledge acquired from anatomical dissection to the determination of the direction of the most important forces acting on the superior articular processes. These findings have been transferred to a 'photoelastic model' and the results finally compared with the arrangement of the trabeculae in the spongy bone as determined from radiographs of sections through the articular processes.

MATERIALS AND METHODS

The muscles and ligaments attached to or near the articular processes of the lumbar vertebrae were dissected in 8 female and 16 male dissecting room cadavers between the ages of 60 and 80 years. Dissecting loops were used to separate the insertions from one another precisely, and to determine the direction of pull of each.

Taking into account the results of earlier investigations (Putz, 1976, 1977), typical third and fourth lumbar vertebrae were chosen from a large collection of macerated specimens, and the superior articular processes cut at two levels with a fine saw about 1 mm in width (Fig. 3). These sections were X-rayed on dental film, in which the

trabeculae of the spongy bone could easily be recognised. The choice of an optimal level at which to make the section was determined empirically in a number of trial sections from its agreement with the line of the medially directed resultant force.

A plane model of the most commonly occurring shape of articular process (Putz, 1977) was made out of Plexiglass (Fig. 4) and examined in polarized light.

The model was then distorted in two different directions, one after the other. It was first subjected to tension in a 'medial' direction. For this purpose the model originally included a side-arm to which wire could be attached. The side-arm was then sawn off and pressure applied *from* the medial side. The trajectories were then obtained by Kummer's method (1956).

RESULTS

Basic anatomical features

The vertebral column was carefully exposed from behind and the muscles and ligaments acting on the superior articular processes of the lumbar vertebrae laid bare. Both the long and short rotator muscles and parts of the multifidus arose from the entire upper border of the superior articular process and from the corresponding accessory process. Individual fibres (particularly those of the deep rotators) took origin also from the mammillary process on the upper border of the articular process. The prevailing direction of the muscle pull – represented by the resultant direction of *all* the divergent fibres – made an angle of approximately 40 degrees with the transverse plane (Fig. 1).

The long and short rotator muscles with the most posterior origins, which subtended an angle of only about 30° at the transverse plane, had the greatest mechanical advantage for producing displacement of the articular process medially.

The small dorsal intertransversarii of the lumbar region ran upwards longitudinally towards the mammillary process. Otherwise there was no strong muscle bundle in this region inserted into the mammillary process. The posterior edge of the mammillary process was braced against the overlying edge of the inferior articular process by a strong wide sheet of fibres (Figs. 1, 2). This sheet of collagenous material, which in the lower lumbar region could be up to a millimetre thick, served to strengthen the fibrous capsule of the zygapophyseal joints.

The joint capsule was relatively thin above (*recessus superior*). It received the stout fibrous sheet just mentioned, and was also strengthened by fibres derived from the interspinous ligament and running to the base of the superior articular process of the vertebra above (Prestar, 1981). In this way, the two mammillary processes of a more caudal vertebra were bound to the vertebra above it (Fig. 1), so that the lower articular processes were supported in a sling.

Interpretation of radiographs

The X-ray photographs taken at different levels of section through the bones (Fig. 3) revealed a typical alignment of the spongy bone, resembling the apex of a pointed arch. Only the mammillary processes themselves remained clear of diagonally crossing trabeculae.

Depending on the level of the section chosen (Fig. 3), there were differences in clarity in the appearance of the spongy bone, the most satisfactory appearance being found in a section running dorsocranially and corresponding to the medially directed resultant pull. Sections made at other angles (for example, the simple transverse

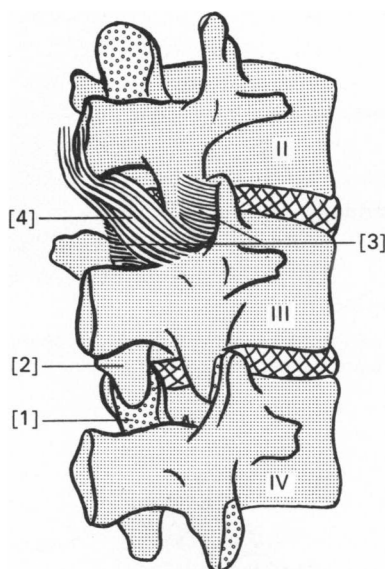


Fig. 1. Dorsolateral view of lumbar vertebrae II-IV. 1, superior articular process; 2, inferior articular process; 3, 'transverse ligaments' of the joint capsule; 4, interspinous ligament.

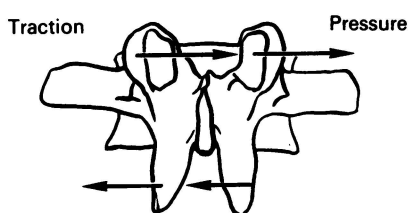


Fig. 2. Diagram showing the forces acting on a superior articular process.

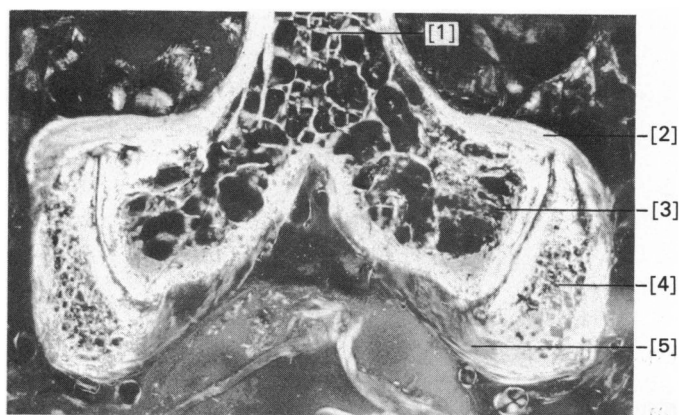
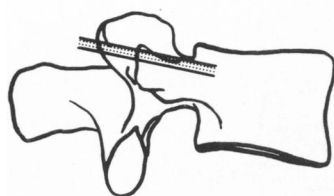
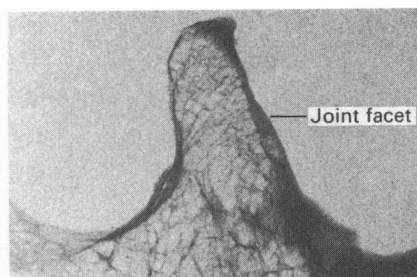


Fig. 3. Horizontal section through the joints between the third and fourth lumbar vertebra. 1, spinous process; 2, 'transverse ligament' of the joint capsule; 3, inferior articular process; 4, superior articular process; 5, ligamentum flavum.



(a)



(b)

Fig. 4(a-b). (a) Lateral view of a third lumbar vertebra showing the plane of section (stippled area) in Fig. 4b. (b) X-ray of a section passing through a superior articular process in the plane indicated in Fig. 4a.

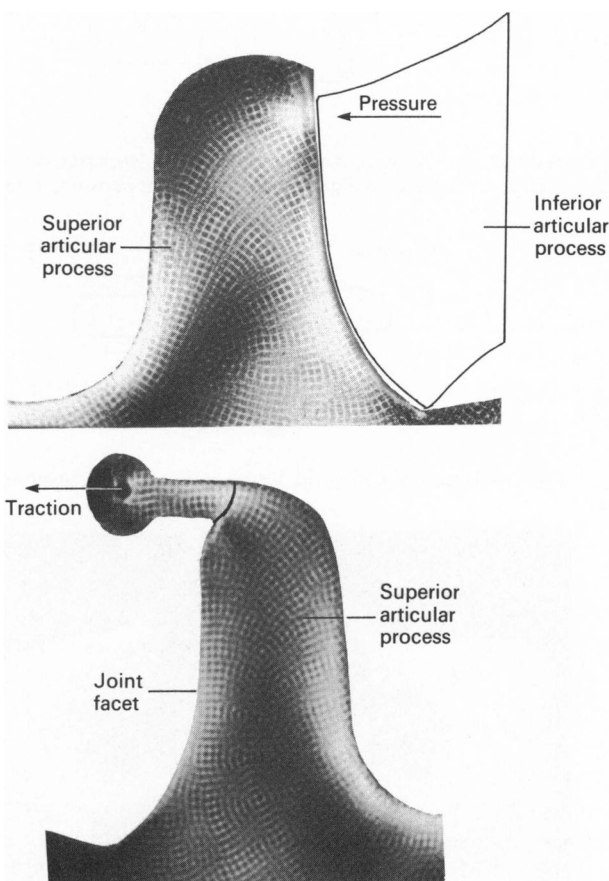


Fig. 5(a-b). Photoelastic model. The trajectory lines have been brought out by means of Kummer's (1956) photographic method. (a) Model under pressure. (b) Model under tension.

section) produced an unclear picture of the spongy bone, and this applied especially to the section nearest the base of the articular process.

The bony trabeculae developed from the medial and lateral cortical bone of the base of the individual articular process and converged towards its apex. At the point where the neural arch was attached to the body, the cortex was remarkably thick.

The photoelastic model

When this model was used, almost identical trajectory lines were produced by both pressure and tension (Fig. 4). These lines were arranged in a series of overlapping pointed arches, converging towards the apex of the model of the process and cutting each other at 90°. Only the part representing the mammillary process remained free from trajectory lines.

During the experimental control of the direction of application of pressure, the anatomical relationship was the same as that already described (Putz, 1976). The transverse pressure was applied to the posterior part of the joint surface. The fact that in the transitional region between the anterior and posterior parts of the lumbar joint surfaces there was almost always a thicker layer of cartilage was sufficient proof that at this place a much more narrowly limited pressure area existed than in other parts of the joint.

The medial component of the tension corresponded closely to the direction of pull of the muscles and ligaments, of which the 'tie-beam' component acting on the mammillary process was the most important part.

DISCUSSION

There is remarkable agreement between the anatomical structure, in particular the internal architecture of the spongy bone, and the results of the photoelastic experiment. If one accepts the claim of Pauwels (1965) that the trabeculae of spongy bone align themselves in accordance with the lines of stress, it can be assumed that the superior articular process comes under stress during bending in the transverse plane, either as a result of direct pressure on the joint or following tension in the joint capsule. These alternating stresses occur during walking and running, etc; at every step there is a pull towards the midline on one side and simultaneously a push from the other. The reason for this is the rotation of the upper part of the body on the pelvis which takes place during the rhythm of walking. With greater overall effort, such as occurs during running or jumping, these rotational forces are noticeably increased.

The degree of rotation, which because of individual variations in the situation of the articular processes can differ largely from person to person, is quite irrelevant. In this connection, mention should be made of the work of Gregersen & Lucas (1967) who investigated the correlation between degree of rotation and bodily habitus. Owing to the parallel movement of the articular processes relative to one another during increasing ventral flexion, the 'tie-beam' action of the superior articular processes is made yet stronger.

The experimental trajectory lines for both pull and push are almost identical. They correspond so well with the arrangement of the spongy bone at the same level that it must be accepted that the internal structure of the superior articular processes is adapted to stress in both directions. Such a finding does not appear to have been previously reported in man.

The form of the articular surfaces of the lumbar vertebrae, the variable thickness of the cartilage, the structure of the spongy bone and also the 'tie-beam' action of the articular processes acting medially indicate a closed system that is capable of taking up all the power of active or passive torsion. The postnatal development of the articular processes may well be determined by the local forces acting on the anterior

or posterior part of the lumbar articular surfaces. Before birth, movement consists largely of flexion/extension movements in the sagittal or coronal plane (Reinold, 1974). It seems that rotation only becomes an important movement of the column after birth. Adaptation (in this case, growth) of the articular processes is bound up with the increasing movements of the child after birth, which is when twisting of the column first causes them to become curved. Relying on the fundamental information obtained by Pauwels (1965), a much better explanation can be produced for the mechanism of development of the articular processes than is provided by arguments based on muscle action alone (Lutz, 1967; Pfeil, 1971).

In conclusion, it may be suggested that the articular processes constitute a closed functional system that provides a 'tie-beam' for the intervertebral discs and can relieve the load at the completion of rotation of the column. As a result of earlier work (Putz, 1976; Niethard, 1981) it is known that the fulcrum during the last part of rotation lies in the region of the joints, which in fact prolongs the weakness of the ventral leverage. In this way the effect of the shearing force on the discs is reduced.

SUMMARY

The bony trabeculae in the superior articular processes of the lumbar vertebrae form a series of overlapping pointed arches that correspond to the lines of stress produced during rotation. By using a photoelastic model, it has been possible to demonstrate that this structural arrangement is a functional adaptation to alternate lateral and medial bending movements. The functional significance of the articular processes is obviously to limit rotation, which can take place in the lumbar segment of the vertebral column during any asymmetrical movement of the body. The alternate bending movements of the superior articular processes arise partly from the laterally directed pressure of the corresponding inferior process, and partly from the medially directed pull of the firm 'transverse strengthening ligaments' of the joint capsule.

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